COHERENT TERAHERTZ RADIATION MONITORS FOR MULTIPLE SPECTRAL BANDS

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Abstract

The SwissFEL Injector Test Facility is destined for demonstrating electron beam parameters that are suitable for FEL operation. Of particular interest is the on-line measurement of longitudinal phase space properties, as this provides insight into the bunch compression process. The spectral distribution of coherent synchrotron or diffraction radiation offers a robust way to assess bunch length and longitudinal profile. Synchrotron radiation is emitted in the fourth bunch compressor dipole; diffraction radiation is emitted as the electron bunches pass through a hole in a titanium foil. The emitted Terahertz radiation has been simulated by the code THz Transport, and the propagation to the detectors has been modeled.

INTRODUCTION

As a preparation for the SwissFEL free electron laser, Paul Scherrer Institut is currently commissioning the SwissFEL Injector Test Facility (SITF) [1]. Electron bunches have been routinely accelerated up to an energy of 130 MeV, and a magnetic chicane that will be used to compress the bunches longitudinally has recently been installed [2]. This bunch compressor can be adjusted to arbitrary angles between 0 and 5 degrees to study details of the bunch compression dynamics. The vacuum chamber follows the motion of the central magnets, and the instrumentation has to be adjusted accordingly. Figure 1 shows an overview of the diagnostics that have been installed and of those that will be installed in the near future.

LONGITUDINAL DIAGNOSTICS

Many methods exist to measure the longitudinal phase space of electron bunches, and several of these will be installed in the SITF. Direct measurements of the bunch distribution can be performed with an RF transverse deflecting cavity (RTDC) [3] and with electro-optical (EO) monitors [4]. Both an RTDC and an EO monitor [5] are foreseen for the SITF. Bunches longer than a picosecond can also be measured with a streak camera. Due to these limitations, such a device is not installed in the SITF.

Measurements in the frequency domain have the advantage that they typically become easier as the bunch length becomes so short that it approaches optical wavelengths. However, since phase information is lost in the detection of the radiation, additional information has to be used to reconstruct the bunch shape unambiguously. A Martin-Puplett interferometer will be installed in the SITF to record the autocorrelation of coherent synchrotron radiation [6].

Finally, the integration of the pulse energy of coherent radiation in a certain frequency range can be used to assess the bunch length [7]. While such bunching monitors do not give an absolute measurement of peak current or pulse length, they allows for a fairly simple set-up that can be used at all times to monitor the stability of the bunch compression process. The signal as a function of bunch length can be cross-calibrated by using the RF transverse deflecting cavity and then used for constant on-line monitoring or feed-backs [8].

BUNCHING MONITORS FOR THE SWISSFEL INJECTOR TEST FACILITY

A bunching monitor consists of three basic components:

- A source of coherently emitted radiation. In most cases, coherent synchrotron, diffraction or transition radiation are used. The radiation is coherent at wavelengths that are larger than the bunch length. In the present case, this corresponds to a frequency in the terahertz range.
- A detector that integrates the pulse energy. Since the frequencies are in the gigahertz to terahertz range, thermal detectors such as pyroelectric detectors, hot electron bolometers or Golay cells have to be used.
- Electronics that amplifies the signal, measures the pulse height or integral, processes the data and makes it available to the control and feedback systems.

For SwissFEL, two possibilities for the emission of radiation are under consideration, coherent synchrotron radiation (CSR) and coherent diffraction radiation (CDR). Table 1 lists the merits of these two approaches.

Note that the radiation that is emitted at terahertz frequencies as the bunch passes the bunch compressor dipole consists of both synchrotron and edge radiation. For SwissFEL parameters, edge radiation actually dominates. Nevertheless, we will refer to this monitor as CSR monitor.

The synchrotron radiation distribution varies with bunch compressor angle. To assess these variations, the distribution on the vacuum window has been modeled (Figure 2). The system has been optimized for the nominal angle of 4.1 degrees, but can be used between 3 and 5 degrees. The calibration of signal as a function of bunch length will be done for different angles.

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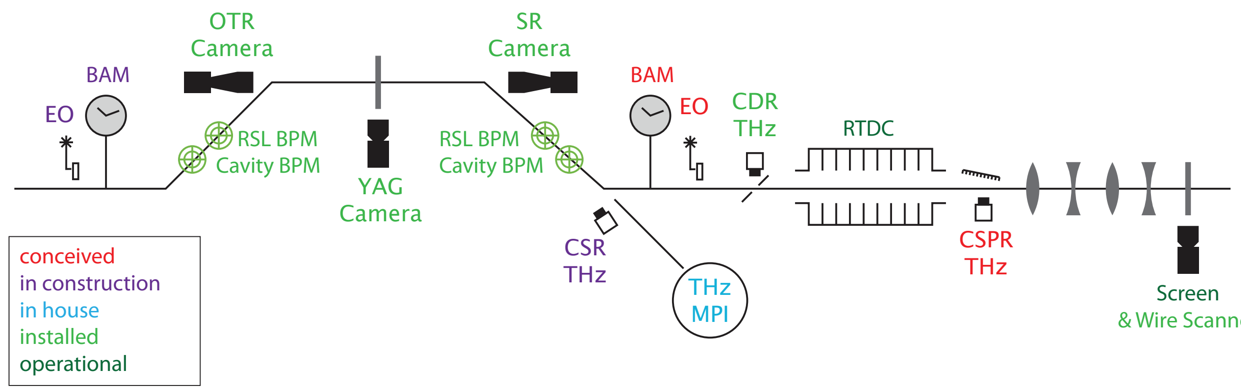

Figure 1: Instrumentation around the bunch compressor in the SwissFEL Injector Test Facility. BAM: Bunch Arrival Monitor, BPM: Beam Position Monitor, CDR: Coherent Diffraction Radiation, CSPR: Coherent Smith-Purcell Radiation, CSR: Coherent Synchrotron Radiation, EOM: Electro-Optical Monitor, MPI: Martin Puplett Interferometer, OTR: Optical Transition Radiation, RSL: Resonant Stripline, RTDC: RF Transverse Deflecting Cavity, YAG: Yttrium Aluminum Garnet.

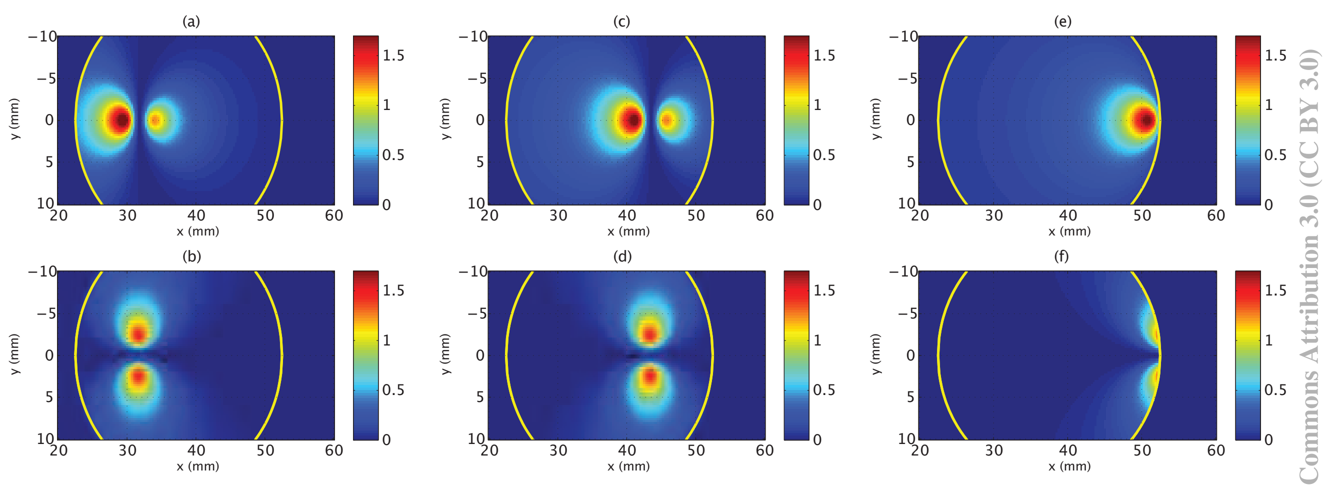

Figure 2: Radiation intensity distribution in arbitrary units on the vacuum window as a function of bunch compressor angle. The wavelength used is 2.85 mm. (a) Horizontal polarization, 3 degrees, (b) vertical polarization, 3 degrees. (c) and (d) 4.1 degrees. (e) and (f) 5 degrees.

In the SITF, two identical setups will be installed, one making use of CSR, the other of CDR. They consist of a collimating mirror, beam splitters that divide the beam into four parts which pass different bandpass filters. A technical drawing of the CSR setup is shown in Figure 3. The synchrotron radiation is coupled out of the accelerator vacuum chamber with a gold-plated mirror and enters the setup which is under a prevacuum through a diamond window.

Silicon beam splitters divide the pulse into four parts, of which three pass through bandpass filters onto pyroelectric detectors. In view of the expected radiation for the different operating modes, the following bands have been selected: (1) from 300 GHz to 1 THz, (2) from 1 to 3 THz, and (3) from 3 to 10 THz. One additional pyroelectric detector is set up to measure the full spectrum.

The beam splitters can be removed remotely to allow the beam to propagate up to the Martin Puplett interferometer situated on the tunnel roof [6].

The setup for coherent diffraction radiation is less complex as the source point does not vary. It consists of a modified profile monitor station [9], where the wire scanner has been replaced with a diffraction radiation iris. The iris consists of a 1 μm thick titanium foil wit a round hole of 3 mm radius. The radius was optimized to be able to extract frequencies up to 10 THz [10].

The foils is under an angle of 45° to the beam and can be inserted into the vacuum chamber by a stepper motor. Figure 4 shows the diffraction radiation foil that has been installed in the SwissFEL Injector Test Facility. The terahertz radiation leaves the accelerator vacuum chamber through a silicon window. For the measurements presented in this paper, the radiation was focused onto a single pyroelectric detector.

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Table 1: Comparison of coherent synchrotron radiation (CSR) and coherent diffraction radiation (CDR) as a source for the SwissFEL bunching monitor.

CSR	CDR
⊕ CSR is a non-invasive THz source, which is always available	⊖ To to produce CDR, an iris needs to be inserted into the beam, which may degrade the beam quality
⊖ The mirrors that collect the light need to be re-aligned after a change in bunch compressor angle	⊕ The alignment is independent of the bunch compressor
⊖ The emitted radiation depends on the magnet current	⊕ The signal is independent of the setting of the bunch compressor
⊖ The radiation that reaches the detector is primarily emitted at the entrance of the fourth dipole, before the bunch compression process is complete	⊕ The radiation is emitted by the fully compressed beam
⊕ A halo of the electron bunch produces the same radiation	⊖ A halo may produce transition radiation, which could be more intense than the CDR
⊖ The system relies on a complicated setup to couple the beam out of the vacuum chamber	⊕ A very simple setup can be used

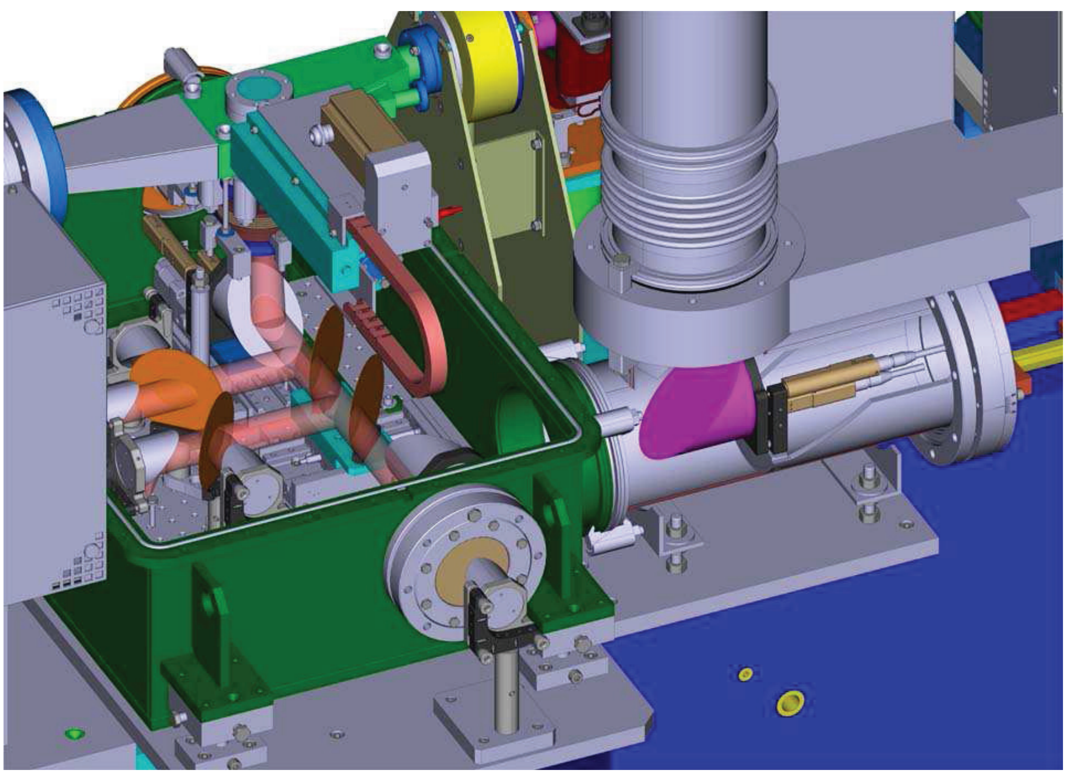

Figure 3: Technical drawing of the planned CSR bunching monitor. The fourth dipole magnet of the bunch compressor can be seen on the left. Four pyroelectric detectors are installed in an evacuated box (shown in green). The transfer line to the Martin Puplett interferometer on the tunnel roof is shown on the right.

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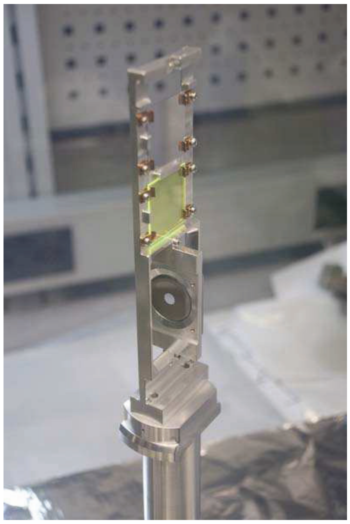

Figure 4: The diffraction radiation foil consists of a 1 μm thick titanium foil that has a round hole with 3 mm radius. It is placed on the same mount as a scintillating screen and an OTR target for a screen monitor.

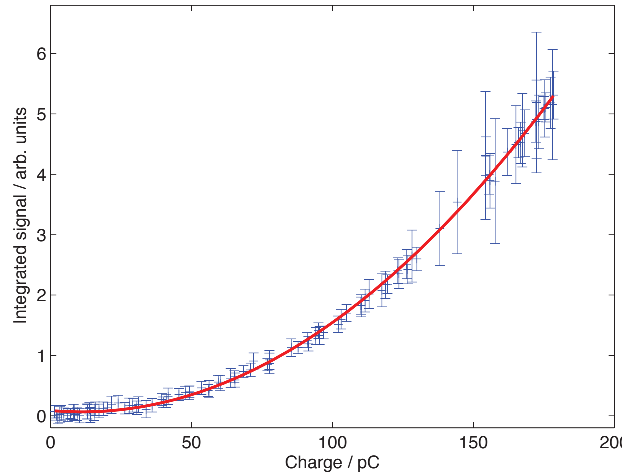

Figure 5: A plot of integrated diffraction radiation as a function of bunch charge shows a quadratic dependency. This measurement was performed without using the bunch compressor. Blue: data, red: quadratic fit.

We are presently building high-impedance pre-amplifiers with differential outputs that will be connected to a data acquisition system based on a field-programmable gate array (FPGA) [11]. This integrates the pulses in real time and makes the result available to the control and feedback systems.

FIRST MEASUREMENTS

First measurements were performed before the bunch compressor installation. To increase the coherent radiation from the long bunches, the pulse stacking scheme for the photocathode laser was modified such that pulse trains of eight bunches of sub-picosecond length were generated. Figure 5 shows a quadratic dependence of the signal integral on the bunch charge, indicating a coherent emission process. The bunch compressor installation in the SwissFEL Injector Test Facility has meanwhile been completed, and measurements with compressed bunches will be performed once the accelerator is operating again.

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